

Unique Marriage of Biology and Semiconductors



ADVANCES in armor for U.S. soldiers and their vehicles have helped save soldiers' lives in overseas conflicts. Yet, many injuries do still occur, such as the loss of a limb from a roadside bomb or other explosion, and sometimes result in the need for a prosthetic device. Over the years, the quality of prostheses has improved, but many remain clumsy or uncomfortable to use. Thanks to a recent Laboratory project, prosthetic devices that are more tightly integrated with the body and more natural to operate may soon be possible. Livermore researchers have successfully combined biological material with semiconductor nanowires in what could be the first step toward vastly improved bioelectronic interfaces. Collaborators on the effort include researchers from the University of California at Berkeley and Davis.

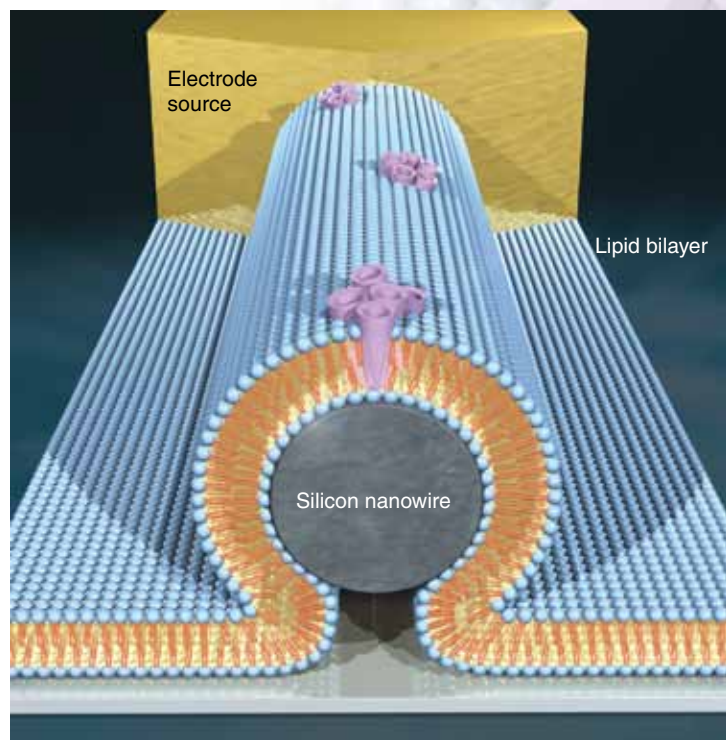
Semiconductor nanowires, made of silicon, are so small that they are considered to have just one dimension. Each nanowire is a few micrometers long but only a few tens of nanometers in width. (One nanometer is a billionth of a meter, half the width of the DNA double helix.) The Livermore team, led by materials expert Aleksandr Noy, has made major advances in the new field of bionanoelectronics by using silicon nanowires wrapped with a layer of fatty organic molecules. The fat, or lipid, becomes a membrane into which a protein or other

molecule can be inserted. Noy explains, "If biological material is deposited directly on silicon, the organic material will die. With the lipid as an interface, the two disparate materials can be combined." This marriage of biomolecules and silicon could greatly increase our ability to communicate with living systems in general.

Modern communication technology relies on electric fields and currents to carry the flow of information. In contrast, biological systems follow an entirely different paradigm that is far more effective and efficient. Living organisms use a sophisticated arsenal of membrane receptors, channels, and pumps to control signal transduction—the ordered sequences of biochemical reactions inside the cell—to a degree that is unmatched by man-made devices. Electronic circuits that make use of biological components, for example as a source of input, could have dramatically greater capabilities, but only if the biological and man-made structures are integrated seamlessly.

Fat Is Good after All

According to Noy, how humans communicate with a computer is very inefficient by biological standards: we push buttons, the machine generates light and sound, and images appear on the screen. "Our



An artist's rendering of the bionanoelectronic device shows how antibiotic molecules (purple) spontaneously insert themselves into the lipid layer (blue) and group together, allowing ion movement through them. When an electrical field is applied to the device, researchers can control ion transport, the first step toward converting biological signals into electronic impulses. (Rendering by Scott Dougherty.)

team's goal is to design a device in which individual biomolecules can communicate directly with semiconductor circuits."

Previous efforts to combine microelectronics with biomolecules have met with varying degrees of success. However, the fairly recent development of nanomaterials, which are comparable in size to biological molecules, has opened up possibilities for successful integration. Other researchers have used carbon nanotubes as carriers for transporting intracellular proteins and DNA. Also, researchers have used silicon nanowires as gene delivery vehicles for mammalian cells. In both instances, the nanomaterial provided a conduit for some substance. However, fully integrating the biological with the nanoelectronic requires a whole new process.

A lipid membrane—the fat we love to hate—turns out to be the perfect medium. The fat mimics a cell wall, and electrostatic interactions make the lipid stick to silicon. The lipid membrane forms a stable, self-healing, virtually impenetrable barrier to ions and small molecules. At the same time, the lipid membrane holds proteins that are vital for almost every cell function, including recognition, transport, and signal transduction. "Lipid membranes can house an unlimited number of protein machines that perform a large number of functions in the cell," says Berkeley collaborator Nipun Misra.

The Device in Action

In 2009, the researchers used protein pores as functional electronic device components. The pores worked as "gate conduits" for turning electrical voltage on and off and for ion

transport in a way that is similar to the processes used by living cells to move salts and other electrolytes from place to place.

The initial bionanoelectronic device consisted of a silicon nanowire connected to a pair of metallic source and drain electrodes. Because bionanoelectronic devices will likely be deployed in an environment comparable to that of the human body—mostly water with a heavy dose of salt—Noy's team replicated such conditions in the experimental setup.

"An exciting possibility is to use the intrinsic electronic functionality of the device to control ion transport through an ion channel in the lipid membrane surrounding the nanowires," says Noy. In experiments, antibiotic molecules spontaneously inserted themselves into the lipid layer and grouped together to form large pores. The researchers found these groups of pores to be of sufficient size for small ions to diffuse through. By applying an electrical field to the device, the team could open and close the biological pores.

Just the First Step

The next step is to directly convert biological signals into electronic impulses, which would require a more sophisticated device made with other nano- and biomaterials. The lipid layers provide a matrix for a virtually unlimited number of transmembrane proteins with different and exciting functionalities. Noy says, "Faster computers, much improved biosensing and diagnostic tools, and prosthetic devices that operate in a whole new way are just a few of the possibilities."

—Katie Walter

Key Words: bionanoelectronics, lipid, nanotechnology, silicon nanowire.

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